Experiment

17

Energy in Simple Harmonic Motion

We can describe an oscillating mass in terms of its position, velocity, and acceleration as a function of time. We can also describe the system from an energy perspective. In this experiment, you will measure the position and velocity as a function of time for an oscillating mass and spring system, and from those data, plot the kinetic and potential energies of the system.

Energy is present in three forms for the mass and spring system. The mass m, with velocity v, can have kinetic energy KE

$$KE = \frac{1}{2}mv^2$$

The spring can hold elastic potential energy, or PE_{elastic}. We calculate PE_{elastic} by using

$$PE_{\text{elastic}} = \frac{1}{2}ky^2$$

where k is the spring constant and y is the extension or compression of the spring measured from the equilibrium position.

The mass and spring system also has gravitational potential energy ($PE_{\text{gravitational}} = mgy$), but we do not have to include the gravitational potential energy term if we measure the spring length from the hanging equilibrium position. We can then concentrate on the exchange of energy between kinetic energy and elastic potential energy.

If there are no other forces experienced by the system, then the principle of conservation of energy tells us that the sum $\Delta KE + \Delta PE_{\text{elastic}} = 0$, which we can test experimentally.

OBJECTIVES

- Examine the energies involved in simple harmonic motion.
- Test the principle of conservation of energy.

MATERIALS

Power Macintosh or Windows PC
LabPro or Universal Lab Interface
Logger *Pro*
Vernier Motion Detector
wire basket
slotted mass set, 50 g to 300 g in 50-g steps
slotted mass hanger
spring, 1-10 N/m
ring stand

PRELIMINARY QUESTIONS

1. Sketch a graph of the height *vs*. time for the mass on the spring as it oscillates up and down through one cycle. Mark on the graph the times where the mass moves the fastest and therefore has the greatest kinetic energy. Also mark the times when it moves most slowly and has the least kinetic energy.

2. On your sketch, label the times when the spring has its greatest elastic potential energy. Then mark the times when it has the least elastic potential energy.

3. From your graph of height *vs*. time, sketch velocity *vs*. time.

4. Sketch graphs of kinetic energy *vs*. time and elastic potential energy *vs*. time.

PROCEDURE

1. Mount the 200-g mass and spring as shown in Figure 1. Connect the Motion Detector to DIG/SONIC 2 of the LabPro or PORT 2 of the Universal Lab Interface. Position the Motion Detector directly below the hanging mass, taking care that no extraneous objects could send echoes back to the detector. Protect the Motion Detector by placing a wire basket over the detector. The mass should be about 60 cm above the detector when it is at rest. Using amplitudes of 10 cm or less will then keep the mass outside of the 40 cm minimum distance of the Motion Detector.

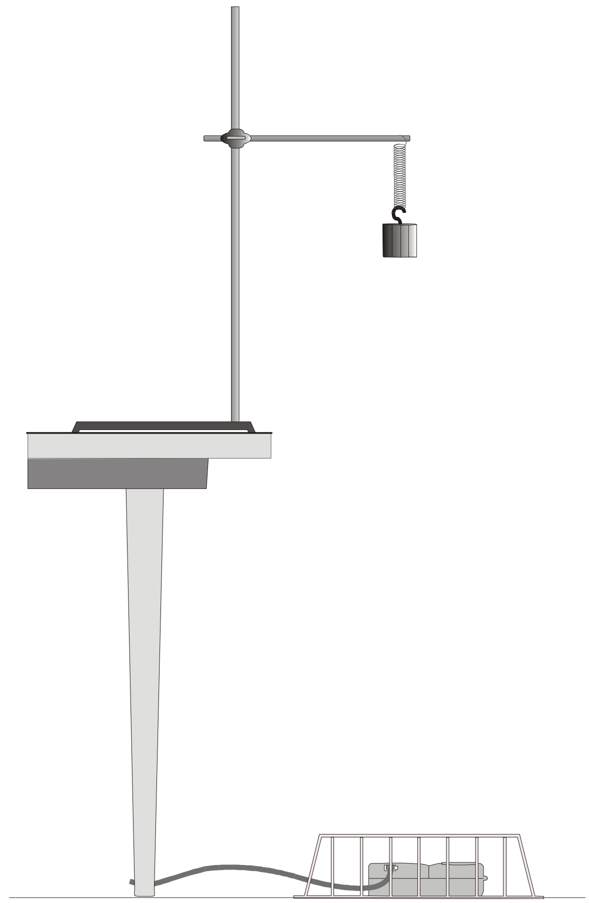

Figure 1

2. Open the Experiment 17 folder from *Physics with Computers*. Then open the experiment file Exp 17a Motion Detector. Two graphs should be displayed on the screen. The top graph is distance *vs.* time, with the vertical axis scaled from 0 to +2 m. The lower graph is velocity *vs.* time with the vertical axis scaled from – 2 to 2 m/s. The horizontal axis on both graphs has time scaled from 0 to 5 s. The data collection rate is 50 samples/s.

3. Start the mass moving up and down by lifting it 10 cm and then releasing it. Take care that the mass is not swinging from side to side. Click [Collect] to record position and velocity data. Print your graphs and compare to your predictions. Comment on any differences.

4. To calculate the spring potential energy, it is necessary to measure the spring constant *k*. Hooke's law states that the spring force is proportional to its extension from equilibrium, or $F = -kx$. You can apply a known force to the spring, to be balanced in magnitude by the spring force, by hanging a range of weights from the spring. The Motion Detector can then be used to measure the equilibrium position. Open the experiment file Exp 17b Spring Constant. Logger *Pro* is now set up to plot the applied weight *vs*. distance.

5. Click [Collect] to begin data collection. Hang a 50-g mass from the spring and allow the mass to hang motionless. Click [Keep] and enter **0.49**, the weight of the mass in newtons (N). Press ENTER to complete the entry. Now hang 100, 150, 200, 250, and 300 g from the spring, recording the position and entering the weights in N. When you are done, click [Stop] to end data collection.

6. Click on the Regression Line tool, [R], to fit a straight line to your data. The magnitude of the slope is the spring constant *k* in N/m. Record the value in the data table below.

7. Remove the 300-g mass and replace it with a 200-g mass for the following experiments.

8. Open the experiment file Exp 17c Energy. In addition to plotting position and velocity, three new data columns have been set up in this experiment file (kinetic energy, elastic potential energy, and the sum of these two individual energies). You may need to modify the calculations for the energies. If

necessary, choose Modify Column ▸ Kinetic Energy from the Data menu and substitute the mass of your hanging mass in kilograms for the value 0.20 in the definition, then click OK. Similarly, change the spring constant you determined above for the value 5.0 in the potential energy column.

9. With the mass hanging from the spring and at rest, click Zero to zero the Motion Detector. From now on, all distances will be measured relative to this position. When the mass moves closer to the detector, the distance reported will be negative.

10. Start the mass oscillating in a vertical direction only, with an amplitude of about 10 cm. Click ▸ Collect to gather position, velocity, and energy data.

DATA TABLE

Spring constant	N/m

ANALYSIS

1. Click on the *y*-axis label of the velocity graph to choose another column for plotting. Uncheck the velocity column and select the kinetic energy and potential energy columns. Click OK to draw the new plot.

2. Compare your two energy plots to the sketches you made earlier. Be sure you compare to a single cycle beginning at the same point in the motion as your predictions. Comment on any differences.

3. If mechanical energy is conserved in this system, how should the sum of the kinetic and potential energies vary with time? Sketch your prediction of this sum as a function of time.

4. Check your prediction. Click on the *y*-axis label of the energy graph to choose another column for plotting. Select the total energy column in addition to the other energy columns. Click OK to draw the new plot.

5. From the shape of the total energy *vs*. time plot, what can you conclude about the conservation of mechanical energy in your mass and spring system?

Write a summary of the concepts you learned in this experiment.